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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
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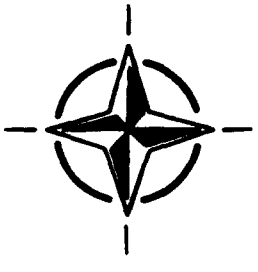
AGARD ADVISORY REPORT 311

Technical Evaluation Report on the Flight Mechanics Panel Symposium on Flying Qualities

(Qualités de Vol)

This Advisory Report was prepared at the request of the Flight Mechanics Panel of AGARD.



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Technical Evaluation Report on the Flight Mechanics Panel Symposium on Flying Qualities

(Qualités de Vol)

by

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This Advisory Report was prepared at the request of the Flight Mechanics Panel of AGARD.

North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

The Mission of AGARD

According to its Charter, the mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community;
- Providing scientific and technical advice and assistance to the Military Committee in the field of aerospace research and development (with particular regard to its military application);
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Exchange of scientific and technical information;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field.

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Preface

The validity of constraining the responses of today's control dominant aircraft to conform to the classic flying qualities criteria derived from stability dominant aircraft experience has been an issue for many years. The introduction of full time visual scene enhancement with sensor fusion, and computer generated, interpreted night scenes, also escalates display dynamics into the arena of flying qualities concern.

Integrated flight and propulsion control schemes and direct force controllers have the potential for completely coupling all the sensors with all the controllers to provide any combination of controlled motion from six independently controlled single-degree of freedom systems to a single coupled six-degrees-of-freedom system.

These new technologies have expanded flight envelopes, reduced drag, increased manœuvrability, provided the framework for practical gust alleviation and active flutter suppression, and provided flexibility for fault-tolerant, damage-adaptive flight controls.

However, the updating of flying qualities criteria has not kept pace with these technological changes.The Flight Mechanics Panel of AGARD therefore decided to organise a Symposium to review flying qualities issues today, and to report progress towards their resolution. The topic areas included: Flight Qualities Experiences on Contemporary Aircraft; Application of Flying Qualities Specifications; Flying Qualities Research and Flying Qualities at High Incidence.

The concluding "Round Table Discussion" provided the Session Chairmen with an opportunity to share with the Symposium attendees their view of the major issues relevant to their session topic which need to be addressed in the future.

This Technical Evaluation Report evaluates the presentations and discussions in each Session, draws relevant conclusions and makes recommendations for future activities in this area.

The papers presented at this Symposium are published as AGARD Conference Proceedings 508.

Préface

Depuis de nombreuses années, la communauté de la mécanique du vol s'interroge sur la validité de la méthode qui consiste à moduler les réponses des aéronefs d'aujourd'hui, qui sont caractérises par la commande, pour qu'elles se conforment aux critères des qualités de vol classiques qui découlent des aeronefs caractérisés par la stabilité.

L'arrivée des systèmes d'enrichissement permanent de l'image combinés avec l'interconnexion des capteurs, ainsi que l'imagerie nocturne crée, analysée par ordinateur, fait passer la dynamique de la visualisation dans le domaine des qualités de vol.

Les systèmes intégrés de commande de vol et de commande de la propulsion et les systèmes de contrôle direct des forces permettent d'envisager le couplage direct de tous les capteurs avec toutes les commandes pour réaliser toute combinaison de mouvement commandé, allant de six systèmes à un seul degré de liberté et à commande individuelle, à un seul système à six degrés de liberté et à couplage intégral.

Ces nouvelles technologies ont eu pour effet d'élargir le domaine de vol, de réduire la trainée, d'accroitre la maniabilité, de fournir l'environnement technologique favorable à l'atténuation des rafales et à la suppression du flottement et d'amener la flexibilité demandée pour la réalisation de commandes de vol insensibles aux défaillances et adaptatives à l'endommagement de l'aéronef.

Cependant, les critères applicables aux qualités de vol n'ont pas suivi ces évolutions technologiques. Le Panel AGARD de la mécanique du vol a donc décidé d'organiser un symposium pour examiner les questions qui se posent dans le domaine des qualités de vol aujourd'hui, et de rendre compte des progrès réalisés en vue de leur résolution. Le symposium a traité des sujets suivants:

—L'expérience acquise dans le domaine des qualités de vol sur les avions modernes;

—La mise en application des spécifications des qualités de vol;

—La recherche en qualités de vol;

et Les qualités de vol à forte incidence.

Le débat "table ronde" qui a clôturé la séance a fourni aux présidents de séance l'occasion d'avoir un échange de vues avec les participants sur les principales questions qui se posent dans ce domaine et qui sont à résoudre à l'avenir.

Ce rapport d'évaluation technique évalue les présentations et les débats de chaque session, en tire des conclusions et fait des recommandations concernant de futures activités lors du symposium sont publiés dans le document AGARD-CP-508.

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Contents

1. INTRODUCTION

The symposium was held at the Chateau Frontenac, Quebec City, Canada, 15-18 October, 1990. Approximately 140 attendees from twelve NATO countries registered at the Symposium, most of them attending through the four days.

1.1 Background and Objectives

The background, theme and objectives of the symposium, as stated in the meeting announcement, were the following:

> The validity of constraining the responses of today's control dominant aircraft to conform to the classic flying qualities criteria derived from stability dominant aircraft experience has been an issue for many years. The introduction of full time visual scene enhancement with sensor fusion, and computer generated/ interpreted night scenes, also escalates display dynamics into the arena of flying qualities concern.
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> Integrated flight and propulsion control schemes and direct force controllers have the potential for completely coupling all the sensors with all the controls to provide a combination of controlled motion from six independently controlled single-degree of freedom systems to a single completely coupled six-degree-of-freedom system.
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> These new technologies have expanded flight envelopes, reduced drag, increased maneuverability, provided the framework for practical gust allevation and active flutter suppression, and provided flexibility for fault-tolerant, damage-adaptive flight controls.
>
> However, the updating of flying qualities criteria has in general not kept pace with these technological changes. The purpose of this Symposium is to review Flying Qualities issues today, and to report progress towards their resolution (emphasis added).

1.2 General Notes

The compilation of papers presented at the meeting are published as Conference Proceedings AGARD CP-508. Included in the proceedings is a transcript of the final "round table" session during which the session chairmen presented for discussion some major points of their session drawn by a small group of the authors and other specialists attending the meeting. These points, addressing the session as a whole, are reflected in the final comments on each session and the conclusions and recommendations sections of this report.

Two points need to be made with respect to the contents of the symposium. On the positive side was the appropriate introduction in Session III to the results of the FMP's Working Group WG17, Handling Qualities of Highly Augmented Unstable Aircraft, reported in AGARD Advisory Report AR-279. This was an effective way to make a larger audience of potential users aware of this thorough summary of existent information on the handling qualities of highly augmented unstable aircraft. On the down side, particular circumstances, the timing of which could not have been anticipated, restricted helicopter/rotorcraft participation in the meeting as authors or attendees. While particular program events and other considerations always affect individual author selection (and even finally attendance!) there were no papers representing the extensive applicable work being done by U.S. government or industry rotorcraft organizations due to their total involvement in the delayed competitive selection of the contractor team for the U.S. Army's LH procurement. The impact resulting from the political status of the V-22, was also a limiting factor. This was a particular disappointment since V-22 tilt wing activities involve the combination of helicopter and fixed wing flight, mirroring the intent of the symposium's planners to gain the benefits of addressing mutual problems in flying qualities and flight control.

2. DISCUSSION

With two keynote addresses, the symposium consisted of twenty-seven papers arranged in four sessions. Two scheduled papers had been withdrawn. The largest session, Research and Applications, was divided into two parts, resulting in five similar sized groupings. This discussion is keyed to the program, Appendix 1, as is the Conference Proceedings volume, CP-508, to provide direct cross-reference for specific papers. For each session after the keynote addresses, brief notes on the individual papers are followed by overall comments on the session.

2.1 Session I Keynote Addresses

From two different backgrounds, the keynote speakers address the past and present of the flying qualities field and put forth some thoughts and issues regarding its future. Both now in management roles in which flying qualities play a part, they were previously directly involved in the field.

Mr. Siewert's remarks reflect his background as a flying qualities engineer and his current position as the overall technology programs director in the U.S. Department of Defense. In consonance with overall aviation progress, he notes the history of flying qualities as an aircraft design and flight evaluation discipline and characterizes the current situation as it has evolved. The point that flying qualities research needs to assume new directions is emphasized. In this regard, he raises three issues for consideration during the symposium and in future work.

> Why should we continue to try to define the characteristics of advanced airplane configurations which no longer exhibit classical response characteristics, such as the short period or dutch roll modes, in those terms?

What is the role of man in the cockpit, and how should this role be addressed in future flying qualities research?

Are flying qualities criteria and the resulting specifications becoming too complex? If so, what are some alternate approaches?

Mr. Coureau, with his long background as an Avions Marcel Dassault test pilot and speaking from his current position as AMD-Breguet Aviation's Flight Safety Manager, complements Mr. Siewert's recap with equally concise remarks from his more pilot oriented view. Particularly for fighter/attack aircraft, he notes both the benefits and some of the drawbacks of current automated flight control systems. The questions he raises are more direct than Mr. Siewert's and he concludes with two general points pertinent to the symposium:

With the increased control system complexity, the establishment of specifications and flying practices will certainly be problematic! The development and subsequent qualifications of software are a difficult task that is hard to control by a Governmental Service. Which are the principles that should be elevated to the rank of regulations? Many of these techniques have not yet been proven operationally.

Everybody is aware that, as in the past, it needs the experience and quality of the humans involved, their team spirit and the close cooperation between the various parties concerned: design engineers, specialized flight test engineers, project test pilots and, above all, the users to define, at a first stage, the requirements and then to correct previously made errors and to guarantee the quality of the product.

2.2 Session II Pilot's View

Reflecting Thomas's experience as a development test pilot, the initial paper (3) in this session sets the stage for the rest of the symposium. The point is made that the evaluation of flying qualities is centered on providing what is needed by the "customer pilot" to accomplish the job for which the aircraft is intended, effectively and safely. The test pilot's role in achieving this objective requires close interaction and full communication between the pilot(s), designers and specialists in the development team from project onset onward. The use of flying qualities requirements as guides, rather than as the basis for approval/acceptance/certification is essential, with pilot evaluation serving the latter purpose. Thomas provides examples, including data for some classical cases, to support this point.

In the following paper, Morse of McDonnell Douglas Helicopter Company discusses from the test pilots viewpoint two developments that improved helicopter flying qualities (4). The two are at opposite ends of the technology spectrum. One, the Advanced Digital Flight Control System (ADFCS), is a highly augmented digital FBW flight control system to provide optimum flying qualities for an attack helicopter throughout its hover, forward flight and combat maneuvering flight regimes. The result intended and achieved was that piloting tasks could be secondary to other flight management workload for a single pilot. The other is a mechanically straight forward system designed to overcome some of the undesirable tail rotor characteristics of single rotor helicopters. Labeled NOTAR, the tail rotor is replaced by a circulation control tail boom, with the basic yawing moment generated by rotor downwash flow over the tail boom, controlling boom side force through Coanda effect by varying airflow out of lengthwise slots along the boom. With hover as well as forward flight to be considered, the helicopter yaw flight control solution is complex. In the case of NOTAR, some fortunate interactions help reduce the resulting pilot control workload. In both developments, pilot interaction from the start, a team approach, and a view of flying qualities requirements as guidelines achieved the objectives of greatly improved flying qualities and reduced pilot control workload. While there is extensive discussion of the design and development approach, problems and solutions for both projects, no general flying qualities data reflecting the results and experience are included.

The last session paper (6) addresses the development of a highly augmented control system having an objective similar to that of the ADFCS in the previous paper, but designed for direct application, including certification, in a production civil transport airplane. Fairineau and Le tron of Aerospatiale cover the flight control aspects of the Airbus A320 lateral directional control system, with emphasis on the direct pilot participation throughout the design and development process. The advantages offered by a FBW system with side-stick controllers were to be achieved while retaining the required safety and other airline requirements with respect to operational reliability and pilot training. The background and design philosophy with respect to flying qualities, flight control laws and the above considerations is well described. Of particular importance was the impact of sensor selection and the resultant potential failure conditions. Significant points for the actual A320 system are covered in more detail, including the particular approach to redundancy, the effect of failure considerations on system design characteristics, and the flight display appropriate to piloting with the resulting flight control. Flight test results, including time histories of several maneuvers are presented. Further considerations for subsequent aircraft, some already being applied on the A330/340 are discussed. The need for a team approach in evolving flight control systems of this type is strongly emphasized.

Based on experience with both classical and highly augmented flight control systems in airplanes and helicopters, the session authors all emphasize the importance of team work and communications among test pilots and all associated engineering discipline specialists in achieving flying qualities goals in aircraft design and development programs. Also noted are the use of ground based simulators appropriate to the particular aircraft and its flight control complexity and the application of flying qualities requirements as guidelines. Issues involving different flight modes, control modes, flight envelope limits and failure situations are discussed for the highly augmented systems. Unfortunately, while pilot assessments are well presented, data of use with respect to criteria are largely omitted - perhaps not surprising for the

'pilot's view . This is particularly regrettable with respect to some of the non-classical control modes for the highly augmented systems.

2.3 Session III Experience with Specifications

Two of the six papers in this session deal directly with the new U.S. Flying Qualities Standard, MIL-STD-1797A, and its application, two with the application of its predecessor, MIL-F-8785C, in specific tactical aircraft programs, and two with criteria for the handling qualities of unstable, highly augmented FBW aircraft. Reflecting the situation discussed in the Introduction, all of these papers relate to fixed wing aircraft. However, the general points made with respect to MIL-STD-1797A would be equally applicable in the case of helicopters.

The new Standard itself is first addressed (7) from the joint viewpoint of two U.S. Air Force authors. Leggett represents the organization responsible for its content, Black the one that applies it in aircraft acquisition/development programs. Of particular note is the Mil-Prime Standard and handbook format with the values of most of the requirements left blank. These are filled in to become a specification for a particular program, with the handbook as Appendix A to the Standard providing guidance and background for this action. Most of the changes from MIL-F-8785C are those necessary for this basic change from Specification to Standard. The various types of requirements are discussed as related to their use in design and flight evaluation. The contract specification aspect gets particular attention. The author's main point, as illustrated in Appendix 2 taken from (7) is the age old flying qualities one that fits with points made strongly in the keynotes and the first Pilot's View paper (3). In the last analysis it is the pilots' evaluation as to whether or not the flying qualities are such that they can accomplish their tasks effectively that determines whether or not any specific characteristic is accepted "as is", or whether change(s) is/are needed. The specification then shifts from its design guidance function to a contractual action document to establish who "pays" for any necessary changes.

Renzo next addresses the application of MIL-F-8785C in the design and development of the joint Italian and Brazilian AMX attack aircraft (8). The AMX is a conventional, subsonic, single engine design with a digital FBW flight control system, using a mechanical backup. With a basically stable aircraft, MIL-F-8785C requirements were used in design, with advantage taken of criteria developed for highly augmented aircraft to address some closed loop tasks as well as the high angle of attack (AOA) and post stall characteristics. The paper addresses these areas, covering analysis results, the use of an AMX configured fixed ground based simulator which included the head up display (HUD) and a large dome, and appropriate flight test results. Data is included for significant points. Using the control capabilities made available by the FBW system and the approach described, the AMX has been provided with good flying qualities over an extended useful flight envelope.

Going into the highly augmented control system sphere, Gibson expands much of his past work on handling qualities criteria for these aircraft (9). The experience gained with the BAe Jaguar FBW and EAP research aircraft, where many of these criteria were applied and tested, has been a major input. Criteria are reviewed and selected examples presented covering the field of flight path and attitude bandwidth, tracking precision, pitch and roll acceleration and sensitivity, pilot induced oscillation(PIO) prevention and enhanced lateral-directional damping. Emphasis in this work is on optimum achievable handling qualities. Research required to meet the issue of optimum versus required handling qualities and to make best use of the capabilities inherent in advanced FBW systems is noted.

Gibson also noted that the EFA has a handling qualities specification making use of the FBW Jaguar and EAP experience. The development of this EFA document is discussed in the next paper (10) by Buchacker et al. The document was based on MIL-F-8785C and, like the AMX flying qualities criteria previously discussed, adapted to the EFA in the same sense as directed under the new MIL-STD-1797A (7). The paper concentrates on areas of the specification where better guidance was considered necessary for application of the criteria (equivalent system approach, small roll step inputs), where new criteria had to be introduced (high order system criterion, carefree handling, pilot evaluation in simulated air-to-air combat) and where the emphasis of existing ones had to be changed or amended (stall and spin, roll performance). Data and appendices are included which support the selection of criteria.

In the second paper dealing with MIL-STD-1797, Black et al address the issue of "off-the-shelf" military procurement of civil certified aircraft, as related to flying qualities (11). The different approach to flying qualities between the MIL spec and the applicable U.S. Civil Federal Aircraft Regulations is noted and examples of recent aircraft so procured are presented. Aircraft procured for missions involving similar flight operations, without major modifications, have generally been satisfactory in their military role. In some cases either the change in flight usage and/or significant modifications have resulted in problems and examples are discussed. The authors note that the advent of FBW civil transports will present new issues for civil certification, and suggest that the applicable military experience be shared/utilized in redefining civil requirements for these aircraft.

Winding up the session, the symposium co-chairman, Mr. Wunnenberg, presented an overview (12) of the final report of AGARD-FMP's Working Group 17, "Handling Qualities of Highly Augmented Unstable Aircraft", AGARD AR-279, as noted in the Introduction. Two other symposium papers (9, 14) address in more detail some of the areas covered in summarized and applicable form in this report.

2.4 Session IV Research and Applications

This session is divided into two parts. Four of the five papers in the first part are fixed wing subjects while the fifth deals with closed-loop control analyses using pilot modeling. The second part has four helicopter papers. The fifth (22) covers handling qualities considerations in the aerodynamic design of unstable fighter aircraft; its discussion is shifted to Session V since it includes high AOA characteristics.

In its place, one of the [illegible] session papers (26) is discussed since it fits with the other helicopter papers.

Part I Fixed Wing and Pilot Modeling

Gerhouse et al initially cover the handling qualities of the USAF/McDonnell STOL and Maneuver Technology Demonstrator (S/MTD) across the spectrum from specification to flight test (13) - much as was done for the AMX in the previous session (8). The S/MTD is a modified F-15 with two-dimensional vectoring and reversing nozzles and an integrated flight/propulsion control system (IFPC), among other advanced technology features. Using a similar approach to that used in the AMX program and the EFA, also discussed in Session III (10), specification requirements were based on MIL-F-8785C with updates; and additional criteria were introduced to deal with the vectored thrust and IFPC modes. Performance and subjective requirements were used where appropriate. Analytical and both fixed and motion based simulations were used for design and development. The authors cover the development, and the flight testing up to the time of the symposium, addressing both individual specification criteria and design methodology. Representative analysis and flight test results are presented. Two areas are identified in which it is considered that the current criteria are inadequate: pitch axis requirements as related to touch down dispersion and directional requirements for target tracking.

Innocenti next addresses flying qualities metrics for roll response (14), reporting on work done in support of Working Group 17's overall project (12). Basically, the ideas behind Gibson's method are extended to develop handling qualities criteria for the roll axis control system. The analysis is performed using an existing data-base for highly augmented fighter type aircraft and parameters such as roll time constant, system's delay and loop sensitivity are considered for designing for good handling qualities and to evaluate control system performance. Gibson's method is noted to have a general applicability in both the pitch and roll axes and is an attractive alternative to the modal requirements of present handling qualities specifications.

Returning to the transport aircraft arena, Nicolas et al cover a joint four country look (France, Germany, Netherlands and UK) at handling qualities guidelines for the design of a FBW flight control system to be used on future aircraft of this type (15). The research was done by an Action Group of the Group for Aeronautical Research and Technology in Europe, (GARTEUR) involving collaboration between ONERA, DLR, NLR and RAE with advice from industry. Attention was directed to the longitudinal control system in the terminal flight phases, with a nominal lateral/directional system used in the simulation. Two primary systems based on flight path rate command, with two conventional backup systems were investigated in the NLR motion based simulator. The transport cab included a sidestick controller and rudimentary head up display (HUD). The suitability of one of the flight path rate control systems, the importance of the HUD, problems in failure transitions to the conventional backup system, and inappropriateness of current criteria for the flight path rate control system design are among the items pointed out. Results include some representative response data. Concern over the inadequacy of the lateral/directional system and its effect on the results suggest the need for further work in this area.

In the fourth paper (16), Bailey summarizes the results of flight tests to evaluate the effect on flying qualities of time delay in the pilot's cueing environment introduced outside the flight control system. These delays were introduced in the tactile cueing, head-up display visual cueing, and the motion and visual cueing during simulation of fighter aircraft. The influence of delay outside of the control system but within the perceptual cueing environment of the fighter pilot can significantly affect flying qualities. The influence is, however, different from the effects due to control system delay.The variable stability NT-33 used for the flight research was also used as a ground based simulator for determining the effects of delays with and without motion cues. As in past flying qualities research experiments, the absence of motion in ground simulation degraded the flying qualities with different results on the effects of the other cueing delays. Appropriate data illustrating and supporting these points are included.

An updated and application oriented presentation (17) by McRuer on the estimation of pilot ratings in closed-loop piloting tasks using pilot modeling concludes Part I. The application of both classical and algorithmic models to multi axis pilot rating estimates has been validated with recent pilot dynamic measurements in simulation experiments. With extensive applicable data the paper serves as a basic current text on the subject.

As in some of the session II and III papers, (8) & (10) for example, development of the S/MTD flying qualities/flight control characteristics were based on MIL-F-8785C as a guide with extensive analysis and ground based simulation used to work out details. The latter were also used to establish integrated flight control laws for the IFPC, much as was done for similar non-classical modes in the helicopter ADFCS of (4). As in that case a process of revising these laws based on continued simulation and analysis governed by flight test experience resulted in achieving program flying qualities goals. Cueing and the relationship between ground based simulation results and flight results must be recognized in this process.

Part 2 Helicopters

As noted in the Introduction, much of the work being done in connection with new military rotary wing developments could not be included in the symposium due to timing. Therefore, all but one of the symposium helicopter papers are concentrated here. One, (24), was actually part of Session V since the paper deals with highly augmented flight control systems, maneuvering flight and agility for helicopters, but is included here for continuity of discussion.

These papers fall in three categories. The first two present flight research results applicable to upcoming

FBW helicopters. The third reports on helicopter flight research dealing with decision height windows in all weather approaches and landings. The second and third were joint Canadian/US programs using Canadian facilities. While these programs had a civil orientation, the results are equally applicable to military helicopters since the test conditions investigated and flight operations concerned are typical for all helicopters. The last two papers address two European FBW flight research helicopter programs.

Both of the first two papers address the flight controller characteristics of FBW helicopters using the variable stability helicopter ("Airborne Simulator") operated by Canada's Institute for Aerospace Research (IAR, formerly NAE, National Aeronautic Establishment). A conventional center stick cyclic control was investigated in the first and the second explored the use of side-arm control.

Current helicopter center stick cyclic controllers trace their force - or lack of force - characteristics to early helicopters and the absence of any relationship to aircraft stability or trim characteristics as found in fixed wing aircraft. The advent of FBW helicopter control systems introduces new dynamic considerations into the handling qualities requirements, and Morgan reports on an initial exploratory investigation of some of these effects (18) The experimental variables were the static and dynamic characteristics of a conventional center-mounted cyclic controller. The cyclic controller mass and spring gradient were varied, while the dynamics of the stick included critically damped, underdamped and overdamped models. Flight tasks exercised three flight modes, high frequency stabilization, gross single axis tasks with off axis stabilization and simultaneous multi axis control. The stick sensitivity was adjusted in proportion to the spring gradient to give constant static sensitivity with respect to applied force. A first order filter was incorporated on an optional basis to reduce the command response bandwidth of the roll channel. The results included indications that cyclic stick characteristics are of considerably less importance than had been previously thought, that large values of overdamping can be tolerated even in low frequency sticks, but that underdamped sticks should be avoided, especially if the resonant frequency of the stick is close to an undesirable and easily excited aircraft mode. Data supporting these initial conclusions are included.

Baillie and Kereliuk cover an extension of the extensive work done at NAE on multi axis side-arm controllers for helicopters over the past decade (19). It was a joint Canada/US sponsored program. While it specifically addresses the use of multi-axis controllers in civil rotorcraft and attendant certification issues, most of the results are equally applicable in the military arena since the flight control tasks are similar. The paper is a good current look at (now) IAR's work with side-arm controllers. Two differently mechanized side-arm controllers (force sensing and deflection sensing) were used and the extent of controller integration was varied from pitch and roll only to fully 4-axis (with collective/ heave and yaw). The pilot opinion and performance flight evaluation results were compared to those for the same range of typical helicopter flight tasks using conventional controls. Extensive discussion and pilot rating results are presented. The deflection sensing side arm controller was the least satisfactory of the three configurations tested; the full 4 axis force sensing side arm controller was as good or better than the conventional controls for most tasks flown. Certification and further flight control issues are noted.

Hoh et al cover another joint Canada/US flight investigation at the Flight Research Laboratory of the IAR (20). The variable stability helicopter was used, but only for establishing handling qualities representative of a current helicopter with a limited authority stability augmentation system using conventional cockpit controllers. Addressed in the study were decision height windows in decelerating IMC (instrument meteorological conditions) approaches. The study stemmed from civil issues, but the overall piloting aspects are common to all helicopter operations in the terminal flight phase. The program was conducted to define the basic limitations of the pilot plus rotorcraft in making the transition from a very low decision height to a steady hover over a helipad. The term "decision-height window" is defined here as the limit of glideslope/ localizer tracking errors and ground speed variations, that can exist at breakout to allow a safe visual transition to hover. The dimensions of the decision-height window can have a significant impact on the required rotorcraft handling qualities, and for setting autopilot coupler and flight director performance standards for decelerating instrument approaches in rotorcraft. This work was an exploratory study to determine important factors and obtain a general idea of order-of-magnitude window dimensions.

Delestrade and Papillier next address modifying an Aerospatiale Dauphin as a variable stability helicopter for investigating the flight control laws applicable in FBW helicopters (21). The paper covers the objectives of the development and planned flight research program and the design and development of the flight control system for the modified Dauphin. Analytical and simulator investigations used in both the development of the control system and the evaluation of alternative control laws are discussed, with an annex containing quantitative analytical results. Early flight testing has confirmed the simulator results and the flight research program is underway.

Similarly addressing FBW helicopters, paper 26 was a last minute substitution in Session V, addressing highly augmented helicopters in agile and precise maneuvering. Pausder and von Grunhagen discuss the need for flight research with respect to handling qualities for future helicopters, the characteristics of the DLR Advanced Technology Testing Helicopter System (ATTHeS) which is a modified BO 105, and their approach to flight research using this variable flight control helicopter, with its model following control system. Some initial results relating to roll response behavior in NOE (nap of the earth) slalom flight, including the effects of control coupling, are presented and discussed. These show that the ATTHeS can be effectively used to explore many of the on-going issues relating to the application of ADS-33C type requirements to future highly augmented helicopters.

Of note is that all of these papers involve variable stability (and control) helicopters. The first three show the range of research that can be conducted using Canada's "Airborne Simulator", a modified Bell 205 that has seen long use. The other two are the newly developed FBW modified Dauphin and the recently upgraded DLR Bo 105, now designated the ATTHeS as an airborne simulator. The increased use and capabilities of these research aircraft reflect the increased sophistication of "all weather" military combat helicopters with single pilot operation and the capabilities of digital FBW flight control systems to use simplified controllers and offer different control modes. These same factors were reflected in the more specific development oriented ADFCS program discussed in paper (4). The research oriented papers provided considerable more specific flight data results than many of the other symposium papers such as (4). In the session issues summary discussion, these largely research oriented authors also reflected the view that the specification "requirements" should be used as guidelines, with better communication of the background and understanding for these requirements to program/design teams. The appropriate use of ground based simulators, with the airborne simulators providing confirmation and real world understanding was also seen as the most efficient and effective use of flight simulation.

2.5 Session V High Angle of Attack

Mangold, in paper (22), presents an excellent transition to the last session, addressing the whole spectrum of initial airplane aerodynamic design, including the high AOA arena. The result is effectively a condensed textbook for the aerodynamic design of a modern unstable fighter as related to handling qualities considerations. Particularly noted are the integrated functions of the flight control system and the resulting requirements for control effectiveness. Control effectiveness must be sufficient to provide the handling qualities required by the pilot throughout the normal flight envelope as well as at high angles of attack - including intentional maneuvers in this region. Both single axis and multi axis conditions must be addressed in defining the full aerodynamic configuration and the matching flight control system characteristics. Application of criteria as discussed in (9), (10), (12) and (14) is illustrated. An integrated aerodynamics and flight control system engineering team is essential in this process. Well chosen and presented graphics with clear discussion of many complex points make this a most useful contribution.

What happens when an older airplane not in accordance with (22) was modified to meet more demanding operational requirements is Sobota's subject in paper (24). In this case stability limited AOA adversely restricted the operational envelope of the B-1B. With the B-i configuration established and increased operational capability requirements for the production B-1Bs, a control system modification was designed to safely extend the necessarily conservative operating limits, providing satisfactory flying qualities, pilot cues of approaching limits and departure resistance in the expanded envelope. Obviously flight testing the resultant Stall Inhibitor System/Stability Enhancement Function, particularly in a very large bomber presented its own challenges. The paper thoroughly covers all the background, technical and operational, to the flight test program and the program conduct and satisfactory results. Avoiding the type of aerodynamically limited characteristics described here is the whole thrust of (22). However flight testing in the near stall area can always be hazardous and the author's discussion effectively addresses the necessary approach.

As a research program the X-29's flight test results have been regularly presented, including those for the full "fighter" flight envelope up to 20 degrees AOA. Walchli and Smith (25) extend this coverage to the results for the second X-29 in the post stall regime. Full maneuvering to 40 degrees AOA and pitch inputs to 66 degrees had been accomplished at the time of the paper. Consistent with the research objectives extensive wind tunnel tests, analysis and simulation preceded and supported the flight testing as AOA was increased into the post stall region. Variations from predictions are noted, with the main points being the lack of any unpleasant surprises, the general ease of control in the high AOA region and the degree of learning regarding the effect on piloting of the flying qualities and performance characteristics. As an initial report, there is excellent qualitative discussion, but no specific data are included. Further data will become available as the X-29 flight research program continues.

Agility has become a rallying point for highly maneuverable fighter aircraft design. Combining flying qualities and performance characteristics, an agreed definition of agility and consequent agreement on agility characteristics and criteria have not been reached. In paper 27, Mazza develops from first principals a fundamental concept of agility and undertakes an initial look at its relationship to flying qualities and maneuvering performance characteristics. This model promises to provide a more rational and practical engineering approach to agility metrics, and further development is planned.

Complementing Mangolds general approach, McKay and Walker in paper 28 address in more detail the implications of designing combat aircraft for high AOA maneuvering, with particular emphasis on the aircraft configuration. Special attention is given to the agility issue, noting that consideration needs to be given to the total weapon system capability, in which aircraft maneuvering characteristics are just one factor. They suggest "Fighting Qualities" as a more adequate term, dealing with the performance of the overall weapon system. This would include the engine, avionics systems, cockpit displays and weapon release aspects. The last are of special concern in relation to the whole question of the functional agility of the system, particularly in the post stall maneuver region. The authors note that further research results are needed in support of design decisions for future fighter aircraft.

In contrast to some of the timing that adversely affected overall symposium content, MBB and Rockwell managed to schedule the first flight of the joint US/German X-31 to fit within the symposium schedule and to deliver a video tape of the flight in time for the last scheduled paper (29) covering the X-31 program. Herbst addresses the background of this

vectored thrust post-stall maneuvering experimental aircraft program, including "supermaneuverability" simulator investigations of some of the issues noted by BAe in the prior paper. Similarly, the design of the X-31 itself is noted to include many of the items discussed in both this paper and the more general paper 22. While the airframe and propulsion performance were limited to reduce costs in the X airplane, the flight control system and cockpit displays are designed to fully and effectively investigate combat type maneuvering in the post stall "Enhanced Fighter Maneuverability" arena. Effective completion of the planned flight program should add significantly to the knowledge base needed to answer many of the questions raised in this area, but not yet answered, as noted in (28).

Several points stand out from the papers discussed under this session. As indicated in earlier sessions, ground based simulation is an essential tool in preparation for and support of flight testing of highly augmented aircraft, whether for research (25) or development (24) purposes. This is particularly true in the high AOA regime, whether approaching limits or extending the flight envelope in the post stall region. Continual updating of this simulation in accordance with flight results is an essential part of the flight test support. Both of these flight programs point to the achievement of satisfactory flight results, whether in the known or expanding envelope, with the full use of all of the analysis and simulation tools now available. The team concept and full communications, here particularly among aerodynamics and flight control system engineers, is again emphasized. Still to come is agreement on agility definition and metrics (27). And hopefully completion of the planned X-29 (25) and X-31 (29) flight research programs will provide real world input to resolution of the issue of high AOA limiting vs post stall maneuvering for future fighter aircraft (28) as well as feedback for criteria establishment and for design, including design trades.

2.6 Flying Qualities and Handling Qualities

Throughout the symposium and the proceedings, the terms "Flying Qualities" and "Handling Qualities" appear, somewhat interchangeably. In his keynote address, Mr. Siewert notes this intermixing and the view of many that this is incorrect. In particular he refers to the symposium's Technical program Co-Chairman, Mr. Key's, expressed views on this difference.

Following the Round Table discussion Key presented his case for a clear distinction between the two terms, at the same time addressing - and integrating - other terms currently used in the community. He used the figure included as Appendix 3, organized to be easily understood by control engineers. Best described "as the way the aircraft flies", Flying Qualities combine the aircraft's stability (and control) characteristics, its maneuverability - essentially the first derivative of its maneuver state - and its agility - the "quickness" with which it can achieve this maneuverability. Noting that pilot Cooper-Harper ratings are meaningless without defined tasks, Handling Qualities, in which these ratings are applied add the tasks, as well as the environment in which the tasks are performed in consort with the Flying Qualities. For the typical fighter-attack aircraft, the combination of its weapon system characteristics and Flying Qualities would define the currently used Fighting Qualities term, which would integrate into the overall Handling Qualities of these aircraft.

At the late stage of the symposium when this proposal was presented, there was little discussion, one way or the other; and neither agreement or disagreement with a suggestion that this concept be adopted. While Key's definition of what fits together, and how, is well conceived, further deliberation is needed. This reviewer, for one, has long understood Flying Qualities to have a task relationship.

Concerned that Handling Qualities assessments and ratings do not correlate well with what the user really needs, Key also made the point that research needs to be done to provide a better definition of Mission Effectiveness as related to Handling Qualities as shown in Appendix 3. Past attempts at this correlation are understood by this reviewer to have been less than successful; pilot adaptability clearly being one contributing factor.

3. CONCLUSIONS

Overall, the symposium met the objectives set forth by the technical committee, though in a much less definitive way than had been anticipated. Unfortunately, major program demands on the military rotorcraft community greatly limited the participation of representatives of this group, either as authors or attendees. However, the papers which were included did represent the current status of helicopter flying qualities related activities. With high AOA and maneuverability getting particular attention in the program, two papers in the final session brought the symposium's papers to a close at a high point. First was a report on X-29 post stall flight experience, with pilot narration of excellent video coverage. This was followed by a technical program look at the joint German/US X-31, accompanied by a video presentation of its first flight.

Collectively, the symposium's papers reflect the full advent of digital computer driven systems. Computer controlled digital FBW flight control systems, along with other digitally controlled pilot interface systems, have greatly changed the focus of flying qualities related efforts in aircraft design and development as indicated by both keynote speakers. Future flying qualities research needs to be redirected accordingly, as pointed out by Mr. Siewert, building on what's already being done in the development phase of current advanced aircraft programs. The expanded use of digital computer and fly by wire systems, rather than any significant increase in aircraft speed/altitude performance, and the emphasis on increased maneuverability/agility in combat aircraft, both fixed and rotary wing, are the major advancements in aeronautics since the 1982 AGARD flying qualities meeting on Criteria for Handling Qualities of Military Aircraft. The impact of these changes on flying qualities activities was effectively reflected in the symposium.

Two other changes in the field are noted. This symposium title is, "Flying Qualities" rather than "Flying Qualities of Military Aircraft", to match the title of the 1982 symposium. By this change, and

symposium content and attendees, the convergence of direction and the extent of mutual interest in common approaches for military and civil aircraft is clear. Similarly, while the flight characteristics of helicopters and fixed wing aircraft have been looked at as separate subjects in the past, digital FBW systems have brought much of the overall flying qualities engineering approaches into a common pattern - as recognized by the symposium planners. The tiltrotor is the epitome of this convergence - unfortunately the result of the V-22's current political status resulted in its participants' non-availability for the symposium.

3.1 General Conclusions

Several views surfaced repeatedly throughout the symposium with respect to achieving mission dictated flying qualities efficiently and effectively in future aircraft development programs. This reviewer would summarize them as follows:

1) The involvement of increased numbers of specialists in ever more disciplines in relation to the overall "pilotability" of new development aircraft places renewed emphasis on the need for operating in a team approach, with the composition varying according to the complexity of the aircraft and its systems.

2) The need for full communications among the team disciplines directly involved in the flying qualities of these aircraft, as well as between them and other design and management groups cannot be over emphasized.

3) With respect to communication, a strong perception exists that there is too much deliberation of the details with respect to flying qualities criteria and requirements and not enough effort on the transmittal of knowledge and understanding.

4) Effective conduct of flying qualities research and application of the results is dependent on this communication being two way between researchers and "users", i.e., development and operational personnel.

5) While there is interchange between the civil aircraft and military aircraft communities, both government and industry, further mutual benefits could be realized by greater emphasis on this interchange.

An additional observation is that, because of the specialization already noted and its carry over into technical meetings and symposiums, the AGARD FMP Flying Qualities Symposiums are unique in the integration of related specialists' interests.

3.2 Technical Conclusions

1) The detailed debate of the 1982 AGARD Criteria for Handling Qualities of Military Aircraft symposium over existing and proposed handling qualities for augmented control system aircraft has given way to a recognition that the various criteria serve different purposes in flight control design and evaluation.

2) New modes of control, generally integrating control functions in ways that vary with the flight tasks, are a major new interest area. Here issues of pilot workload in a broader sense than in traditional flying qualities assume new importance, and pilot assessment becomes all important.

3) Appropriately selected ground based simulation is an essential tool in these integrated flight control systems, but final evaluation still depends on flight results.

4) The range of criteria which are needed for highly augmented and integrated flight control systems must include those needed as extremes of the operating limit are approached and those for emergency (failure) conditions.

5) Initial results of the X-29 high AOA post stall flight research are encouraging in terms of satisfactory handling qualities results, but full assessment awaits completion of the planned flight research program.

6) The issue of limiting AOA vs providing "carefree handling" throughout the conventional and post stall envelop is still subject to disagreement; the results of the X-29 and X-31 programs should contribute towards eventual resolution.

7) There continues to be a need for an agreed definition of combat aircraft agility.

3.3 Meeting Format

1) Session chairmen and authors meeting as a group to work out each session's input to the Round Table is an effective concept, but the dynamics of the symposium itself and other panel member commitments during the symposium period, make it difficult to implement.

4. RECOMMENDATIONS

4.1 General

The following are suggested for AGARD FMP consideration as recommendations to appropriate military and/or research authorities:

1) Technical authorities in NATO countries in which aircraft are developed under government sponsorship should ensure that the results of that portion of any development effort which addresses flying qualities (in the broadest sense of the term) be made available in a usable form to all segments of government and industry to the extent permissible by security, proprietary, or other restraints.

2) Similarly, research authorities in those countries sponsoring advanced development projects should ensure that the results of project efforts relating to flying qualities considerations are documented as part of project reporting.

3) Interchange in the flying qualities area (at least) should be emphasized between groups

responsible for military acquisition/development and civil certification, both for applying the best knowledge base to advanced technology aircraft, and to minimize difficulties in military off-the-shelf acquisition and operation of civil certified aircraft.

4) Continued effort in all highly maneuverable aircraft test programs and supporting research should be devoted to reaching agreement on a definition of agility and the accompanying metrics and criteria.

5) Flying qualities research in multiple axis and integrated mode flight control should be expanded, establishing suitable criteria for design and evaluation.

4.2 Symposiums

1) AGARD FMP should continue to hold periodic Flying Qualities Symposiums as one of the few joint meetings of the variously involved specialists that addresses this fundamental area.

2) As the current new tactical fixed wing, helicopter and tilt rotor aircraft now under development reach the operational stage, and flying qualities related information can be shared, a follow-on Flying Qualities Symposium should be planned. This would include the results of on-going research programs, such as the X-29, X-31, NASA High AOA Research Vehicle, Dauphin FBW and ATTHeS, and others as appropriate. Emphasis would be in two areas: Flying qualities criteria in the current sense as adapted for highly augmented aircraft throughout the full usable maneuvering envelope, and the entire area of non-classical integrated control modes. Included in the latter would be the development process as related to piloting effectiveness, interaction with other digitally driven interface systems, and possible general criteria that can be used in design and evaluation.

3) The effectiveness of this symposium's Round Table concept, having each session's chairmen and authors meet and collectively develop a session input, would be improved by having a facilitator for this group. This person would be an attendee less involved in the symposium itself and the other FMP activities conducted during the symposium period, and should be a recognized individual in the session field, preselected, and receiving the papers ahead of time (before the symposium for the first day at least). If the session co-chairmen desire, he could also be the Round Table speaker for the session.

APPENDIX 1

PAPERS PRESENTED

SESSION I - KEYNOTE ADDRESSES

(1) Flying Qualities Research - Quo Vadis?
R. F. Siewert, Department of Defense, U.S.

(2) L'Adaption des Qualities de Vol au Pilote et a la Mission
J. Coureau, Avons Marcel Dassault - Breguet Aviation, FR

SESSION II - PILOT'S VIEW

(3) The Art of flying Qualities Testing
D. Thomas, D. Thomas Flight Test, GE

(4) ADFCS and NOTAR ™: Two Ways to Fix Flying Qualities
C. S. Morse, McDonnell Douglas Helicopter Co., US

(5) Withdrawn

(6) Qualities de Vol Lateral D'un Avion de Transport Civil Equipe de Commandes de Vol - Experience de L'A320
J. Farineu & X. Le tron, Aerospatiale, FR

SESSION III - EXPERIENCE WITH SPECIFICATIONS

(7) MIL-STD-1797 is not a Cookbook
D. B. Leggett, WRDC and G. T. Black, AFSC, US

(8) Flying Qualities Experience on the AMX Aircraft
B. Renzo, Aeritalia, IT

(9) The Development of Alternate Criteria for FBW Handling Qualities
J. C. Gibson, BAe, UK

(10) Development of MIL-8785C into a Handling Qualities Specification For A New European Fighter Aircraft
E. Buchacker, WTD, H. Galleithner, DLR, R. Koehler, DLR and
M. Marchand, DLR, GE

(11) Do Civil Flying Qualities Requirements Address Military Missions for "Off-the-Shelf" Procurement
G. T. Black, AFSC, W. A. Grady, USAF and D. C. McDonald, USAF, US

(12) Handling Qualities of Highly Augmented Unstable Aircraft; Summary of an AGARD-FMP Working Group Effort
H. Wuennenberg, Dornier Luftfahrt, GE

SESSION IV - FLYING QUALITIES RESEARCH AND APPLCIATIONS (PART I)

(13) The Handling Qualities of the STOL and Maneuver Technology Demonstrator from Specification to Flight Test
D. J. Moorhouse, WRDC, K. D. Citurs and R. W. Thomas, McDonnell Douglas, and M. R. Crawford AFFTC, US

(14) Metrics for Roll Response Flying Qualities
M. Innocenti, Universita di Pisa, IT (now at Auburn University, US)

(15) Handling Qualities Guidelines for the Design of FBW Flight Control Systems for Transport Aircraft
O. P. Nicholas, RAE, UK, W. P. de Boer and J. A. J. van Engelen, NLR, NE, H. T. Huynh, ONERA FR and D. Shafranek, DLR, GE

(16) The Flying Qualities Influence of Delay in the Fighter Pilots Cueing Environment
R. E. Bailey, Calspan, US

(17) Estimation of Pilot Ratings via Pilot Modeling
D. McRuer, Systems Technology Inc., US

SESSION V - FLYING QUALITIES RESEARCH AND APPLCIATIONS (PART 2)

(18) An Initial Study of the Influence of Control Stick Characteristics on the Handling Qualities of a FBW Helicopter
J. M. Morgan, IAR/NRC, CA

(19) An Investigation into the Use of Side-Arm Control for Civil Rotorcraft Applications
S. W. Baillie and S. Kereliuk IAR/NRC, CA

(20) Determination of Decision-Height Windows for Decelerating IMC Approaches in Helicopters
R. H. Hoh, Hoh Aeronautics, US; S. W. Baillie and S. Kereliuk, IAR/NRC, CA; and J. Traybar, FAA Technical Center, US

(21) Evaluation des Lois de Pilotage Evolvees sur DAUPHIN N
P. Delestrade, Aerospatiale and D. Papillier, CEV, FR

(22) Integration of Handling Quality Aspects into the Aerodynamic Design of Modern Unstable Fighters
P. Mangold, Dornier - Luftfahrt, GE

(23) Withdrawn

SESSION VI - FLYING QUALITIES AT HIGH ANGLE OF ATTACK AND LARGE AMPLITUDE MANEUVERING

(24) B-1B High AOA Testing in the Evaluation of a Stall Inhibitor System
M. S. Sobata, AFFTC, US

(25) Flying Qualities of the X-29 Forward Swept Wing Aircraft
L. A. Walchli, WRDC and R. Smith, NASA, US

(26) Handling Qualities Evaluations for Highly Augmented Helicopters
H. J. Pausder and W. von Grunhagen, DLR, GE

(27) Agility: A Rational Development of Fundemental Metrics and their Relationship to Flying Qualities
C. J. Mazza, NADC, US

(28) A Review of High Angle of Attack Requirements for Combat Aircraft
K. McKay and M. J. Walker, BAe, UK

(29) X-31A at First Flight
W. B. Herbst, MBB, GE

ROUND TABLE DISCUSSION

Chaired by H. Wuennenberg

APPENDIX 2

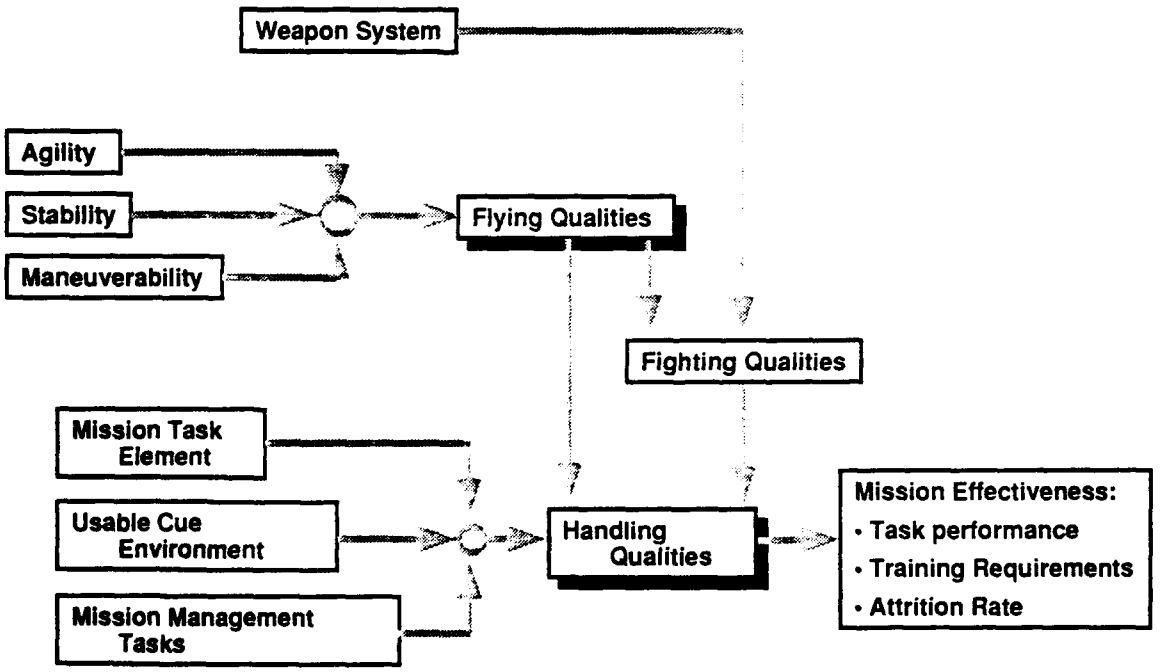
SPECIFICATION COMPLIANCE

PILOT OPINION	Meets Specification	Doesn't Meet Specification
Pilots Like It	OK	Prove It
Pilots Dont' Like It	Fix It	Fix It

POSSIBLE OUTCOMES OF FLYING QUALITIES EVALUATIONS

APPENDIX 3

HANDLING QUALITIES AND FLYING QUALITIES



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14. Abstract

The validity of constraining the responses of today's control dominant aircraft to conform to the classic flying qualities criteria derived from stability dominant aircraft experience has been an issue for many years.

The introduction of full time visual scene enhancement with sensor fusion, and computer generated/interpreted night scenes, and the use of integrated flight and propulsion control schemes and direct force controllers have expanded flight envelopes, reduced drag, increased manœuvrability, provided the framework for practical gust alleviation and active flutter suppression, and provided flexibility for fault-tolerant, damage-adaptive flight controls.

However, the updating of flying qualities criteria has in general not kept pace with these technological changes. The Flight Mechanics Panel of AGARD therefore decided to organise a Symposium to review flying qualities issues today, and to report progress towards their resolution. The topic areas included: Flying Qualities Experiences on Contemporary Aircraft; Application of Flying Qualities Specifications; Flying Qualities Research and Flying Qualities at High Incidence.

This Technical Evaluation Report evaluates the presentations and discussions in each Session, draws relevant conclusions and makes recommendations for future activities in this area. The papers presented at this Symposium are published as AGARD Conference Proceedings 508.

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